Nuclear Power Plant Systems Notes

The purpose of this presentation is to introduce students to the fundamental structures and primary operating systems for pressurized water reactor (PWR) and boiling water reactor (BWR) power plants through the use of graphics to show what these structures and systems look like. In the U.S. there were originally 3 companies that designed PWRs – Westinghouse, Combustion Engineering, and Babcock & Wilcox – and one company that designed BWRs – General Electric.

For convenience, we will begin at the outside of the nuclear power plant and work our way in.

Slide 2 – Palo Verde nuclear plant

- photograph of 3-unit Palo Verde nuclear plant
- each unit generates 1400 megawatts of electricity
- supplies electrical needs of >4 million people

Slide 3 – PWR containment building

- graphic illustrates typical containment building for PWR
- entire nuclear portion of plant contained within this reinforced concrete structure
- building is ultimate barrier for fission product retention in event of accident

Slide 4 – PWR primary coolant system

- graphic illustrates components of typical PWR primary coolant system; system consists of
  - reactor vessel containing nuclear fuel
  - reactor coolant pumps
  - steam generators for transfer of reactor-generated heat that produces steam for conventional steam power plant
  - pressurizer to control primary coolant system pressure
  - piping connecting system components
- primary coolant system entirely contained within reactor containment building

Slide 5 – PWR core and control rod system configuration

- graphic shows configuration of reactor core and control rod system inside PWR pressure vessel
- nuclear reactor core consists of around 150 fuel assemblies
- control rod system used for operational core reactivity control; that is, to control fission chain reaction rate
  - boron in control rods captures neutrons that would otherwise produce fission in uranium-235 fuel

- control rods enter reactor core from above and control rod drives located at top of reactor vessel

Slide 6 – PWR nuclear fuel assembly

- graphic illustrates one of nuclear fuel assemblies that make up PWR core
- typical fuel assembly consists of fuel rods containing nuclear fuel pellets, guide tubes, and instrument tubes as shown on right in graphic
- guide tubes accommodate insertion/removal of control rods or incore instrumentation
- instrument tube used only for incore instrumentation

Slide 7 – PWR boric acid reactivity control system

- boric acid used as “burnable poison” (i.e., neutron absorber) in reactor coolant for long-term core reactivity control
  - — boric acid pumped from boric acid tank into reactor coolant
  - — boron in boric acid, like boron in control rods, captures neutrons that would otherwise produce fission in U-235 fuel
    - ✓ boron gets used up by absorbing neutrons (i.e., converted to carbon-12) during reactor operation; hence name “burnable poison”
    - ✓ boric acid concentration in reactor coolant higher at beginning of reactor core life than at end of core life to accommodate core reactivity change as U-235 used up over time

Slide 8 – PWR operational heat removal system

- graphic illustrates normal heat removal during reactor operation
- heat generated in reactor core produces steam in steam generators located inside reactor containment building
  - — heat from high pressure primary coolant water transferred to low pressure secondary coolant water to create steam in steam generator, with cooler primary coolant water pumped back to reactor core
- steam from steam generators flows through piping to conventional steam cycle power plant consisting of steam turbine, electrical generator, and condenser
- water from steam cycle power plant condenser pumped back to steam generators by feedwater pumps
- PWR plants have two, three, or four recirculating primary coolant loops, depending on plant design, to remove heat from reactor core

Slide 9 – PWR shutdown heat removal system

- following nuclear reactor shutdown, heat that continues to be generated in fuel from radioactive decay removed by shutdown cooling system (also known as residual heat removal system)

- primary coolant removed from reactor vessel outlet piping, then pumped through heat exchanger and back to reactor vessel inlet piping
- heat removed from shutdown cooling heat exchanger by component cooling water system

Slide 10 – Brown's Ferry nuclear plant
- photograph of the 3-unit Brown's Ferry nuclear power plant
- each unit generates 1200 megawatts of electricity

Slide 11 – BWR containment structures
- graphic illustrates evolution of containment structures used for boiling water reactors
- containment structures consist of drywell surrounding BWR pressure vessel and pressure suppression pool known as wetwell

Slide 12 – BWR Mark I containment structure
- drywell consists of concrete enclosure with steel liner
- wetwell is steel torus half-filled with water

Slide 13 – BWR Mark II containment structure
- steel vessel encloses both drywell and wetwell

Slide 14 – BWR Mark III containment structure
- drywell and wetwell contained within steel-reinforced concrete building

Slide 15 – BWR primary coolant system
- graphic illustrates components of typical BWR primary coolant system; system consists of
  - reactor vessel containing nuclear fuel
  - recirculation pumps for modulating coolant flow through reactor core
  - feedwater piping
  - steam piping
  - recirculation system piping
- primary coolant system entirely contained within drywell containment structure

Slide 16 – BWR core and control rod system configuration
- graphic shows configuration of reactor core and control rod system inside BWR pressure vessel
- control rod system used mainly for long-term core reactivity control
- because steam separators and dryers located in top of reactor vessel, control rods enter reactor core from below and control rod drives located at bottom of reactor vessel

Slide 17 – BWR nuclear fuel assembly

- graphic illustrates one of nuclear fuel assemblies that make up BWR core
- typical fuel assembly consists of full length and part length fuel rods containing nuclear fuel pellets, and water “rods” (provide additional neutron moderation within fuel assembly)

Slide 18 – BWR control rod assembly

- graphic shows construction of BWR control rod assembly, known as control blade
- crucifix control blade composed of individual neutron-absorbing control rods

Slide 19 – BWR fuel assembly and control blade configuration

- unlike PWR control rods, BWR control rods not located within fuel assemblies
- graphic shows how BWR control blade located between four BWR fuel assemblies

Slide 20 – BWR feedwater flow reactivity control

- In BWR, feedwater flow through reactor core is primary means for operational core reactivity control; that is, to control fission chain reaction rate

Slide 21 – BWR operational heat removal system

- graphic illustrates normal heat removal for BWR
- heat generated in reactor core boils primary coolant to create steam
- steam passes through moisture separator and steam dryer units in top of reactor vessel and flows through piping to conventional steam cycle power plant consisting of steam turbine, electrical generator, and condenser
- water from steam cycle power plant condenser pumped back to reactor core by feedwater pumps

Slide 22 – BWR shutdown heat removal system

- in BWR, primary coolant removed from recirculation pump outlet piping, pumped through residual heat removal heat exchanger and back to recirculation pump inlet piping
- heat removed from residual heat removal heat exchanger by service water system